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Clinical Paper

# Characteristics of regional cerebral oxygen saturation levels in patients with out-of-hospital cardiac arrest with or without return of spontaneous circulation: A prospective observational multicentre study☆

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ABSTRACT

*Aim:* Our study aimed at filling the fundamental knowledge gap on the characteristics of regional brain oxygen saturation ($rSO_2$) levels in out-of-hospital cardiac arrest (OHCA) patients with or without return of spontaneous circulation (ROSC) upon arrival at the hospital for estimating the quality of cardiopulmonary resuscitation and neurological prognostication in these patients.
*Methods:* We enrolled 1921 OHCA patients from the Japan – Prediction of Neurological Outcomes in Patients Post-cardiac Arrest Registry and measured their $rSO_2$ immediately upon arrival at the hospital by near-infrared spectroscopy using two independent forehead probes (right and left). We also assessed the percentage of patients with a good neurological outcome (defined as cerebral performance categories 1 or 2) 90 days post cardiac arrest.

*Abbreviations:* CPC, cerebral performance categories; CPR, cardiopulmonary resuscitation; EMS, emergency medical services; J-POP, Japan – Prediction of Neurological Outcomes in Patients Post-cardiac Arrest Registry; OHCA, out-of-hospital cardiac arrests; PCAI, post-cardiac arrest intervention; ROSC, return of spontaneous circulation; $rSO_2$, regional cerebral oxygen saturation.

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*Results:* After 90 days, 79 (4%) patients had good neurological outcomes and a median lower $rSO_2$ level of 15% (15–20%). Compared to patients without ROSC upon arrival at the hospital, those with ROSC had significantly higher $rSO_2$ levels (56% [39–65%] *vs.* 15% [15–17%], respectively; $P<0.01$), and significantly correlated right- and left-sided regional brain oxygen saturation levels ($R=0.94$ *vs.* 0.66, respectively). In both groups, the percentage of patients with a good 90-day neurological outcome increased significantly in proportion to their $rSO_2$ levels upon arrival at the hospital ($P<0.01$).
*Conclusion:* Our data indicate that measuring $rSO_2$ levels might be effective for both monitoring the quality of resuscitation and neurological prognostication in patients with OHCA.


## 1. Introduction

Recent guidelines for cardiopulmonary resuscitation (CPR) increased the focus on methods ensuring that high-quality CPR is performed in all resuscitation attempts.[1,2] A reliable, inexpensive, non-invasive physiological monitor that will increase our ability to optimize CPR for individual patients of cardiac arrest should be developed. This is necessary to advance the delivery of optimal CPR and ultimately save more lives.[3–5]

On the other hand, the advent of systematic bundled post-cardiac arrest interventions (PCAIs) has increased the likelihood of patients surviving out-of-hospital cardiac arrests (OHCAs) while maintaining good neurological conditions.[6–11] Hence, the importance of estimating the severity of brain damage and the neurological prognostication for OHCA patients has been emphasized in the literature.[6,9,10,12,13]

Regional cerebral oxygen saturation ($rSO_2$) is a measure of cerebral perfusion that is obtained noninvasively *via* near-infrared spectroscopy (NIRS) and can be monitored in patients with cardiac arrest.[14–18] We previously reported that $rSO_2$ measured upon the patient's arrival at the hospital might help to predict neurological outcomes in OHCA patients.[19,20] The optimal cut-off point identified in our study was an $rSO_2$ >42%. These data suggest that $rSO_2$ monitoring might be useful for (1) monitoring the quality of CPR for patients before the return of spontaneous circulation (ROSC), and (2) determining a neurological prognostication for all OHCA patients.

When continuous $rSO_2$ monitoring of patients undergoing pre-hospital CPR is performed,[21] $rSO_2$ values of patients with and without ROSC have to be assessed. This will likely cause some confusion regarding which $rSO_2$ values (those during the resuscitation state *vs.* those post resuscitation) should be adopted for prognostication and precise triage to PCAIs. To establish methods for quality monitoring of resuscitation and neurological prognostication, $rSO_2$ levels might therefore have to be interpreted according to ROSC status in patients with and without ROSC on arrival at the hospital.

Achieving ROSC after an OHCA has a significant effect on cerebral circulation and oxidation. Using receiver operating characteristic analyses, our previous report demonstrated the different optimal cut-off points for predicting good neurological outcomes between OHCA patients with and without ROSC upon arrival at the hospital ($rSO_2$ >62% and >21%, respectively).[19] However, few studies have focused on how ROSC upon arrival at the hospital affects $rSO_2$ monitoring and sensitivity for the neurological prognostication after an OHCA.

To address this knowledge gap, we conducted a descriptive study aimed at performing a precise comparison of $rSO_2$ values in patients undergoing resuscitation and those post resuscitation upon arrival at the hospital.

## 2. Methods

### *2.1. Study design and setting*

The Japan – Prediction of Neurological Outcomes in Patients Post-cardiac Arrest Registry (J-POP) is a prospective multicentre cohort study. Fifteen tertiary emergency care hospitals in Japan participated in this study from 15 May 2011 to 30 August 2013. Among the consecutive 3086 OHCA patients who were transported to the hospitals, 1921 patients were enrolled in the study. Individuals who were unresponsive during and after resuscitation upon arrival at the hospital following an OHCA were included in our study. The exclusion criteria included trauma, accidental hypothermia, age <18 years, completion of the "Do Not Attempt Resuscitation" form, and a Glasgow coma scale (GCS) score of >8 upon arrival at the hospital.

The study protocol was approved by the institutional review board or ethics committee at each participating hospital. The details of the J-POP registry design and its main outcomes have been published elsewhere.[19]

### *2.2. Emergency medical services and cardiopulmonary resuscitation in Japan*

In Japan, emergency lifesaving technicians are permitted to insert tracheal tubes and administer intravenous adrenaline (epinephrine).[22] All emergency medical service (EMS) providers perform CPR according to current CPR guidelines.[2,23] However, EMS providers are not permitted to terminate CPR in the field.

### *2.3. Resuscitation procedures after arrival at the hospital*

All patients received advanced life support in accordance with the national guidelines for resuscitation after arrival at the emergency department. If sustained ROSC (restoration of a palpable pulse that is sustained for at least 20 min) was not obtained using standard advanced life support, patients whose initially documented electrocardiograph rhythm was ventricular fibrillation or pulseless ventricular tachycardia received extracorporeal CPR with extracorporeal circulatory support or a cardiopulmonary bypass. When patients achieved ROSC, therapeutic hypothermia was induced once their systolic blood pressure exceeded 90 mmHg and their GCS score was between 3 and 8.[24–26] All procedural decisions were made at the discretion of the attending physician(s).

### *2.4. Patient characteristics and cardiac arrest*

Data were collected prospectively based on the Utstein style.[27,28] Baseline patient characteristics and in-hospital data were collected from medical records and databases.[19]

Cardiac arrest was defined as the absence of spontaneous respiration, a palpable pulse, and stimuli responsiveness.[27–29] The arrest was presumed to be of cardiac origin unless it was caused by cerebrovascular disease, respiratory disease, external factors (*e.g.*, drug overdose or asphyxia), or other non-cardiac factors. Cardiac or non-cardiac origin was determined clinically by the physician-in-charge.

### 2.5. Near-infrared spectroscopy

Upon arrival at the hospital, two disposable near-infrared spectrometer (INVOS™ 5100C; Covidien, Boulder, CO, USA) probes were carefully applied on both sides of the patient's forehead (right and left) to monitor $rSO_2$ using two channels. After several seconds of stabilization, $rSO_2$ was monitored using the probes for a minimum of 1 min.[19,30–33] The measurable range of $rSO_2$ was 15–100%; hence, if $rSO_2$ values were very low (<15%), the patients' $rSO_2$ values were shown as 15%.

First, the right- and left-sided $rSO_2$ values in each patient were compared. We then selected the lower of the two $rSO_2$ values and used it to analyze the patients' distribution of $rSO_2$ levels upon arrival at the hospital and the association between $rSO_2$ levels upon arrival at the hospital and the patients' neurological outcomes.

### 2.6. Neurological outcomes

The primary study endpoint was the patients' 90-day neurological outcomes, which were categorized according to the Glasgow-Pittsburgh cerebral performance categories (CPCs) as described in the Utstein style guidelines.[27,28] The guidelines categorize CPC 1 (good performance) and CPC 2 (moderate disability) as 'good neurological outcomes', and CPC 3 (severe disability), CPC 4 (vegetative state), and CPC 5 (brain death or death) as 'poor neurological outcomes'. The CPCs of individual patients were determined by at least two physicians-in-charge who were blinded to the $rSO_2$ readings that were obtained upon arrival at the hospital.

### 2.7. Statistical analyses

Unpaired *t*-tests or Mann–Whitney *U*-tests were conducted for unpaired comparisons, and a $\chi^2$ test or Fischer exact test was used to examine differences between categorical variables. The strength of the association between two ranked variables was calculated with Spearman correlation. Finally, the Cochran Armitage Trend Test was used to test the potential association between a variable with two categories and variables with ordered levels. JMP version 10.0.0 (SAS Institute, Cary, NC, USA) was used for all statistical analyses. All reported probability values are 2-tailed, and $P < 0.05$ was considered statically significant.

The authors had full access to the data and assume responsibility for its integrity. All authors have read and agree with the contents of this manuscript.

### 2.8. Ethical considerations

The study protocol conformed to the Guidelines for Epidemiologic Studies issued by the Ministry of Health, Labor, and Welfare of Japan.[34] The study protocol was approved by the institutional review board or ethics committee of each participating medical institution. The requirement for informed consent was waived by the institutional review boards or ethics committees. Our work complies with the principles laid down in the Declaration of Helsinki.

## 3. Results

### 3.1. Patient characteristics and neurological outcomes

During the study period, J-POP accumulated data on 3086 consecutive OHCA patients who were referred to the 15 participating hospitals. After exclusions, 1921 patients were included in our analysis (Fig. 1). Among these, 148 (8%) achieved ROSC and 1773 (92%) did not achieve ROSC when $rSO_2$ was monitored upon their arrival at the hospital. 1382 (72%) were pronounced dead in the emergency department. Of the remaining 539 patients, 115 (6%) survived for at least 90 days. After 90 days, 60 (3%), 19 (1%), 9 (0.5%), and 27 (1%) patients had CPCs of 1, 2, 3, and 4, respectively. Accordingly, 79 patients (4%) were considered to have good neurological outcomes (CPC 1 or 2, Fig. 1).

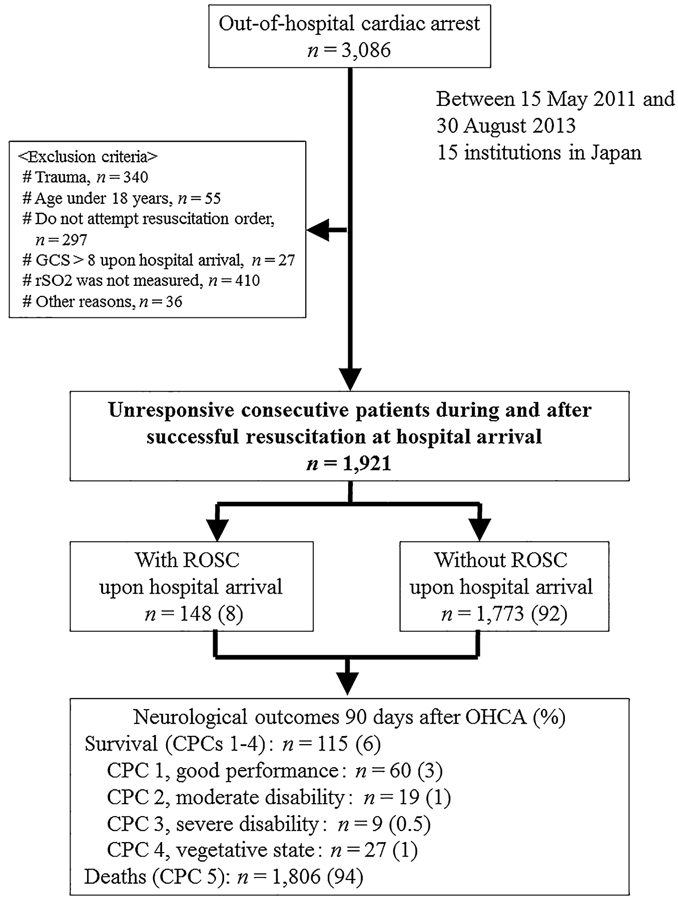


**Fig. 1.** Study design and neurological outcomes. CPC, cerebral performance categories; GCS, Glasgow coma scale; ROSC, return of spontaneous circulation; $rSO_2$, regional cerebral oxygen saturation.

Among patients with ROSC upon arrival at the hospital ($n = 148$), 22 (15%) were pronounced dead in the emergency department. Of the remaining 126 patients (85%), 71 (48%) survived for at least 90 days. After 90 days, 45 (30%), 11 (7%), 7 (5%), and 8 (5%) patients had CPCs of 1, 2, 3, and 4, respectively. Thus, 56 patients (38%) were considered to have good neurological outcomes (Table 1).

Among patients without ROSC upon arrival at the hospital ($n = 1773$), 1360 (77%) were pronounced dead in the emergency department. Of the remaining 413 patients (23%), 44 (2%) survived for at least 90 days. After 90 days, 15 (0.9%), 8 (0.5%), 2 (0.1%), and 19 (1%) patients had CPCs of 1, 2, 3, and 4, respectively. Hence, 23 patients (1%) in this patient group were considered to have good neurological outcomes (Table 1).

Compared to patients with ROSC upon arrival at the hospital, patients without ROSC frequently had unfavorable characteristics such as OHCA at home, no witnesses, no bystander-initiated CPR, and no shockable rhythms. These patients frequently underwent prehospital procedures such as intravenous epinephrine administration and defibrillation, as well as procedures after arrival at the hospital such as therapeutic hypothermia, coronary angiography, and primary percutaneous coronary intervention. In contrast, patients with ROSC upon arrival at the hospital frequently had favorable outcomes such as survival to hospital admission, survival after 90 days, and good neurological outcomes (Table 1).

**Table 1**
Patient characteristics and neurological outcomes.

| Characteristics | Total ($n$ = 1921) | With ROSC ($n$ = 148) | Without ROSC ($n$ = 1773) | $P$-value* |
|---|---|---|---|---|
| Age in years, median (IQR) | 76 (63–84) | 72 (57–84) | 76 (63–84) | 0.14 |
| Male sex (%) | 1167 (61) | 100 (68) | 1067 (60) | 0.08 |
| Location of cardiac arrest (%) | | | | <0.01 |
| Home | 1319 (69) | 67 (45) | 1252 (71) | |
| Nursing home/assisted living | 177 (9) | 21 (14) | 156 (9) | |
| Public building | 76 (4) | 13 (9) | 63 (4) | |
| Street | 114 (6) | 19 (13) | 95 (5) | |
| Other | 235 (12) | 28 (19) | 207 (12) | |
| Type of bystander/witness status (%) | | | | <0.01 |
| No witness | 970 (50) | 34 (23) | 936 (53) | |
| Family members | 528 (27) | 52 (35) | 476 (27) | |
| EMS | 122 (6) | 14 (9) | 108 (6) | |
| Others | 301 (16) | 48 (32) | 253 (14) | |
| Bystander-initiated CPR (%) | 481 (25) | 69 (46) | 412 (23) | <0.01 |
| Origin of cardiac arrest (%) | | | | 0.60 |
| Presumed cardiac | 1195 (62) | 89 (60) | 1106 (62) | |
| Non-cardiac | 726 (38) | 59 (40) | 667 (38) | |
| Initially documented rhythms on the scene of the cardiac arrest (%) | | | | <0.01 |
| VF/pulseless VT | 205 (11) | 40 (27) | 165 (9) | |
| PEA | 487 (25) | 43 (29) | 444 (25) | |
| Asystole/unknown | 1229 (64) | 65 (44) | 1164 (66) | |
| Prehospital procedures (%) | | | | |
| Advanced airway devices | 1098 (57) | 80 (54) | 1018 (57) | 0.44 |
| Intravenous epinephrine administration | 508 (26) | 67 (45) | 441 (25) | <0.01 |
| Defibrillation | 261 (14) | 53 (36) | 208 (12) | <0.01 |
| Emergency call to arrival at the hospital in min, median (IQR) | 32 (26–40) | 33 (27–40) | 32 (26–40) | 1.00 |
| Rhythm at $rSO_2$ measurement (%) | | | | |
| VF/pulseless VT | 87 (5) | N/A | 87 (5) | N/A |
| PEA | 383 (20) | N/A | 383 (22) | |
| Asystole | 1303 (68) | N/A | 1303 (73) | |
| Other (pulse detectable at arrival at the hospital) | 148 (8) | 148 (148) | N/A | |
| Procedures after arrival at the hospital (%) | | | | |
| Extracorporeal CPR | 121 (6) | 9 (6) | 112 (6) | 1.00 |
| Therapeutic hypothermia | 203 (11) | 72 (49) | 131 (7) | <0.01 |
| Coronary angiography | 153 (8) | 53 (36) | 100 (6) | <0.01 |
| Primary percutaneous coronary intervention | 65 (3) | 22 (15) | 43 (2) | <0.01 |
| Survival to hospital admission | 539 (28) | 126 (85) | 413 (23) | <0.01 |
| Neurological outcomes at 90 days after OHCA (%) | | | | <0.01 |
| Survival (CPCs 1–4) | | | | |
| CPC 1, good performance | 60 (3) | 45 (30) | 15 (0.9) | |
| CPC 2, moderate disability | 19 (1) | 11 (7) | 8 (0.5) | |
| CPC 3, severe disability | 9 (0.5) | 7 (5) | 2 (0.1) | |
| CPC 4, vegetative state | 27 (1) | 8 (5) | 19 (1) | |
| Deaths (CPC 5) | 1806 (94) | 77 (52) | 1729 (98) | |
| Good neurological outcomes (CPCs of 1 or 2) at 90 days after OHCA (%) | 79 (4) | 56 (38) | 23 (1) | <0.01 |

CPC, cerebral performance categories; CPR, cardiopulmonary resuscitation; EMS, emergency medical service; IQR, interquartile range; N/A, not applicable; PEA, pulseless electrical activity; $rSO_2$, regional cerebral oxygen saturation; ROSC, return of spontaneous circulation; VF, ventricular fibrillation; VT, ventricular tachycardia; OHCA, out-of-hospital cardiac arrest.

* Comparing patients with ROSC and those without ROSC upon arrival at the hospital.

**Table 2**
Regional cerebral oxygen saturation levels upon arrival at the hospital.

| $rSO_2$ upon arrival at the hospital, % median (IQR) | All patients | With ROSC | Without ROSC | $P$-value* |
|---|---|---|---|---|
| Right side ($n$ = 1905) | 15 (15–24) | 58 (43–67) | 15 (15–21) | <0.01 |
| Left side ($n$ = 1899) | 15 (15–25) | 57 (42–68) | 15 (15–22) | <0.01 |
| Lower value ($n$ = 1921) | 15 (15–20) | 56 (39–65) | 15 (15–17) | <0.01 |
| Higher value ($n$ = 1921) | 17 (15–28) | 60 (44–70) | 17 (15–25) | <0.01 |

ROSC, return of spontaneous circulation; $rSO_2$, regional cerebral oxygen saturation.

* Comparing patients with ROSC to those without ROSC upon arrival at the hospital.

### 3.2. *Regional cerebral oxygen saturation upon arrival at the hospital*

We were able to examine right-sided $rSO_2$ in 1905 (99%) and left-sided $rSO_2$ in 1899 (99%) patients. Table 2 shows the $rSO_2$ levels of the patients upon arrival at the hospital by ROSC status. The median (IQR) rSO2 levels on the right and left sides were 15% (15–24%) and 15% (15–25%), respectively ($P$ = 0.95), and the median (IQR) lower and higher rSO2 levels were 15% (15–20%) and 17% (15–28%), respectively. We found significantly higher $rSO_2$ levels in patients with ROSC upon arrival at the hospital than in those without ROSC ($P$ < 0.01).

The association between right- and left-sided $rSO_2$ is depicted in Fig. 2. The Spearman's correlation coefficients were 0.74, 0.94, and 0.66 among all patients, patients with ROSC, and patients without ROSC upon arrival at the hospital, respectively.

### 3.3. *Distribution of regional cerebral oxygen saturation levels upon arrival at the hospital and 90-day neurological outcomes*

$rSO_2$ was <15% in 16/148 (11%) and 1256/1773 (71%) of patients with or without ROSC upon arrival at the hospital, respectively (Fig. 3a, Supplemental Table). Of the patients with or without ROSC upon arrival at the hospital, only 1/16 (6%) and 5/1773 (0.5%), respectively, had good 90-day neurological outcomes, respectively (Fig. 3b). The percentage of patients with a good 90-day neurological outcome increased significantly in proportion to the lower $rSO_2$

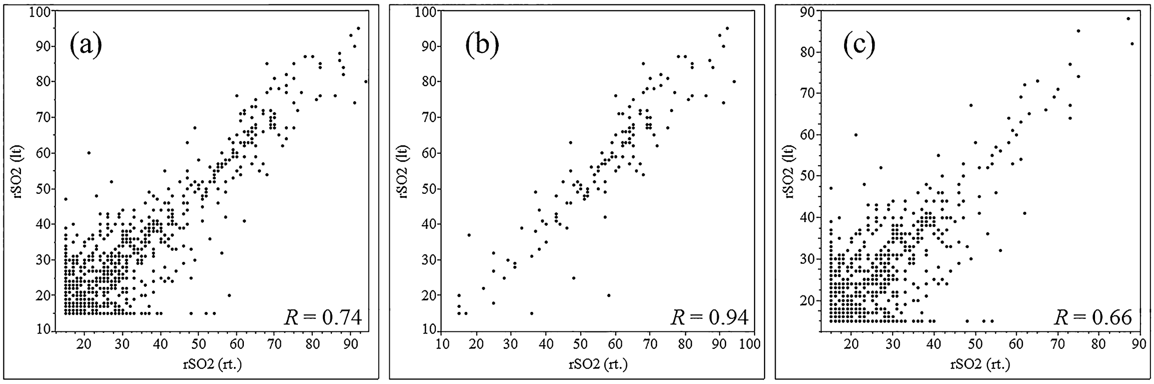


**Fig. 2.** Correlation of right- and left-sided regional cerebral oxygen saturation levels. (a) All patients, (b) patients with ROSC upon arrival at the hospital, (c) patients without ROSC upon arrival at the hospital. R, Spearman's correlation coefficient; ROSC, return of spontaneous circulation; $rSO_2$, regional cerebral oxygen saturation.

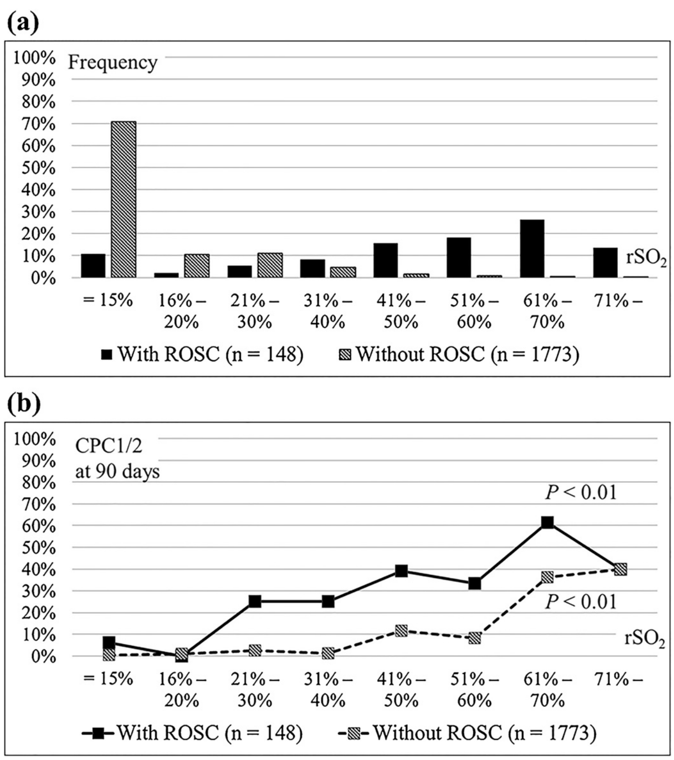


**Fig. 3.** Distribution of the lower levels of regional cerebral oxygen saturation upon arrival at the hospital and 90-day neurological outcomes. (a) Number of patients in each $rSO_2$ category. (b) CPC 1 or 2 after 90 days by $rSO_2$ category. ROSC, return of spontaneous circulation; $rSO_2$, regional cerebral oxygen saturation.

levels measured upon arrival at the hospital, irrespective of their ROSC status ($P < 0.01$ for both) (Fig. 3b).

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2015.07.013

## 4. Discussion

Our results show that the characteristics of $rSO_2$ monitoring (median $rSO_2$ levels, the association between right- and left-sided $rSO_2$, and the distribution of $rSO_2$ levels) were different between OHCA patients with and without ROSC upon arrival at the hospital. On the other hand, the rate of 90-day good neurological outcomes increased in proportion to the patients' $rSO_2$ levels irrespective of their ROSC status upon arrival at the hospital (Fig. 3b), implying that $rSO_2$ evaluation is effective for both monitoring the quality of resuscitation and neurological prognostication.

Compared to patients without ROSC upon arrival at the hospital, those with ROSC had significantly higher $rSO_2$ levels, and their right- and left-sided $rSO_2$ levels showed a statistically significant association. Because EMS staffs are not permitted to terminate CPR in the field in Japan, all patients without ROSC upon arrival at the hospital had undergone continuous standard CPR by EMS staff. $rSO_2$ was <15% in 71% of patients without ROSC upon arrival at the hospital. Very few of these patients (0.5%) had good 90-day neurological outcomes. Thus, continuous standard CPR by EMS staff did not remarkably improve $rSO_2$ levels in our study population. Moreover, the correlation of right- and left-sided rSO2 levels was lower in these patients. This might have been caused by (1) inadequate cerebral perfusion and oxidation following OHCA by standard CPR, (2) generation of signal noise originating from the NIRS system during CPR, or (3) cerebral hypoperfusion and hypoxia inducing severe brain damage specific to the post-cardiac arrest syndrome. Future studies employing continuous $rSO_2$ monitoring prior to the patients' arrival at the hospital are needed.

The percentage of patients with good 90-day good neurological outcomes increased significantly in proportion to their $rSO_2$ levels irrespective of their ROSC status upon arrival at the hospital, implying that adequate cerebral perfusion and oxidation were vital to protect from brain damage after the OHCA. To our surprise however, $rSO_2$ levels did not improve to levels >15% even with continuous standard CPR by EMS staff in 1256/1773 (71%) of patients without ROSC upon arrival at the hospital. Of these patients, 5/1773 (0.5%) had a good 90-day neurological outcome. Moreover, even when patients achieved ROSC upon arrival at the hospital, 16/148 (11%) exhibited the lowest possible $rSO_2$ (15%) levels, and only 1/16 (6%) patients had good 90-day neurological outcomes. Low $rSO_2$ levels combined with a poor neurological prognosis implies severe brain damage due to cerebral hypoperfusion and hypoxia.

Our data demonstrate that $rSO_2$ evaluation might be effective for both the monitoring of the quality of resuscitation in patients without ROSC upon arrival at the hospital and neurological prognostication in all non-traumatic OHCA patients.

## 5. Limitations

This study has several limitations. Studies have shown that healthcare providers often have difficulty detecting a pulse[35–37]; thus, our ROSC measure might have been unreliable. Second, as we reported previously,[19] continuous $rSO_2$ monitoring would be desirable prior to arrival at the hospital. However, the absence of NIRS devices in ambulances makes this impossible. Third, NIRS measurements of $rSO_2$ levels only reflect cerebral perfusion in the superficial layers of limited frontal lobe areas. Even though $rSO_2$ measured by NIRS has been shown to compare well to $rSO_2$ measured through jugular venous oxygen saturation in normal subjects,[38] $rSO_2$ may not be a reliable marker of brain tissue oxygen partial pressure under critical cerebral conditions such as post cardiac arrest syndrome.[19,30,31] Fourth, we could not blind the investigators to the patients' $rSO_2$ values because $rSO_2$ monitoring requires real-time visual confirmation. As per a pre-specified protocol, all patients received the best available therapy, regardless of their $rSO_2$ levels.[19] However, we could not eliminate the possibility that low $rSO_2$ levels might have influenced the decision to terminate resuscitation. Fifth, as EMS providers in Japan are not permitted to terminate CPR, most OHCA patients who were treated by EMS personnel were transported to emergency departments; therefore, a very small proportion of patients with documented rhythms at the scene of cardiac arrest demonstrated ventricular tachycardia/fibrillation, and the majority had very poor 90-day neurological outcomes.[22,39] Therefore, the external validity of this study might be limited. Sixth, this study was an observational study.[19] Seventh, the duration of CPR likely affects patient outcomes. However, we could not use integrate this factor into our analyses because of the poor quality of the data. Eighth, we had to exclude 446/2367 (19%) patients from this study because of a deviation from the study protocol. Finally, the measurable range of $rSO_2$ using INVOS$^{TM}$ 5100C is limited to 15–100%; hence, we could not precisely examine cerebral perfusion in patients with very low $rSO_2$ values (<15%).

## 6. Conclusions

Our study shows that the $rSO_2$ monitoring characteristics and neurological prognoses differed in OHCA patients with and without ROSC upon arrival at the hospital. However, irrespective of ROSC attainment, the percentage of patients with good 90-day good neurological outcomes increased in proportion to their lower $rSO_2$ levels upon arrival at the hospital. In conclusion, our data indicate that $rSO_2$ evaluation might be effective for both, monitoring the quality of resuscitation and neurological prognostication.

## Conflict of interest statement

Dr. Nishiyama has conducted an investigator-sponsored study (Covidien, Japan) entitled "Prehospital $rSO_2$ Study" ("Pre-hospital Resuscitation for Sustaining Cerebral Oxidation: Observational Cohort Study").

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